PACS numbers: 42.65.Ky; 42.81.Dp
DOI: 10.1070/QE2002v032n01ABEH002117

Controlling the width of a femtosecond continuum generated in a small-diameter fibre

S.M.Kobtsev, S.V.Kukarin, N.V.Fateev

***Abstract*. The control of the width of a continuum generated in a tapered germanium-doped silica fibre with the waist diameter of ~ 3 μm is experimentally demonstrated for the first time. The width of the continuum was controlled by varying the wavelength of chirped femtosecond pump pulses near the zero-point of the group velocity dispersion of the fibre. The width of the continuum at the -20-dB level was varied from 98 to 790 nm by tuning the central wavelength of 80-fs, 0.6-nJ input pulses from 789 to 847 nm.**

Keywords: *tapered fibre, continuum generation, femtosecond pulses.*

The spectrum of femtosecond pulses can be substantially transformed upon their propagation in optical fibres of diameter several microns with a core that partially or entirely borders air (hereafter, referred to as microfibres), which were fabricated based on holey fibres [1, 2], or in tapered fibres. This is manifested in the appearance of individual spectral components whose central wavelength can be longer [3] or shorter [4] than the wavelength of the initial pulses, as well as in the broadening of the spectrum [5], including the supercontinuum generation [6 – 8].

Microfibres are characterised by the shift of the wavelength λ_d of the zero group velocity dispersion (GVD) to the visible spectral region and by a small effective area of a mode, resulting in an increase in nonlinear refraction. This allows one to generate a supercontinuum due to the self-phase modulation (SPM) of ultrashort nonamplified nanojoule pulses from a Ti:sapphire laser propagating in a microfibre [8]. The supercontinuum was generated in paper [8] by pumping tapered germanium-doped silica fibres with the waist diameter of $\sim 1.5 - 2.5$ μm in the region of the anomalous GVD (the pump wavelength 850 nm was longer than λ_d). The width of the supercontinuum at the -20-dB level was from ~ 450 to 1175 nm, depending on the pump-pulse power.

In this paper, we studied experimentally the evolution of a continuum generated in a microfibre upon variation of the wavelength of initially chirped femtosecond pump pulses in the intermediate region between anomalous and normal GVD of the microfibre. We assumed that the compensation or an increase in the initial chirp of the pump pulses upon a change in the GVD sign would modify the continuum spectrum. In addition, it was interesting to find out whether it is possible to fabricate microfibres of diameter several micrometres from a standard single-mode optical fibre under laboratory conditions. So far, only one research group [8] have managed to fabricate such microfibres.

To fabricate microfibres with a core that entirely borders air, we used a SMF-28 Corning optical fibre. The initial fibre with the cladding diameter 125 μm was drawn in a hydrogen-burner flame. The drawing could be performed in several stages, each time the fibre diameter being reduced by a factor of $\sim 3 - 5$. The diameter of the thinnest microfibres was $\sim 40 - 60$ times smaller than the initial diameter, being equal to 2 – 3 μm. The waist diameter was calculated with an error of about 0.2 μm. The waist length of microfibres was 70 – 140 mm, while the length of the intermediate region (between the large and small diameters) was 20 – 25 mm. Microfibres kept in dustproof cases were rather stable to mechanical and acoustic perturbations and were preserved for a long time (over month and longer).

The microfibres were pumped by a FEMoS Ti:sapphire laser (developed at the Laboratory of Laser Systems at Novosibirsk State University) through a $8^{\times}/0.2$ microobjective. The pump pulses had duration of 80 fs, a pulse repetition rate was 80 MHz, and a peak pulse power was 14 kW (an average power was 90 mW). The spectral width (FWHM) of the pump pulse was 21 – 27 nm. The calculated chirp parameter of the output 40-fs laser pulses that have propagated through optical isolation elements, the micro-objective, and the initial (not drawn) piece of the fibre of length 5 – 6 cm was approximately 2. The radiation coming from the microfibre was collimated by a lens and directed to an optical spectrum analyser. The spectra were analysed in the 400 – 2000-nm region with a scanning MDR-4 monochromator equipped with a germanium photodetector and the system for spectra recording in a PC.

The greatest variation in the spectral width of the emission emerging from the microfibre observed upon changing the pump-pulse wavelength in the region from ~ 790 to 850 nm was achieved for microfibres 2.6 – 2.8 μm in diameter. The wavelength of the zero GVD for these microfibres is close to 800 nm, while at the edges of the tuning region of the laser wavelength, the calculated GVD for microfibres of diameters 2.6 and 2.8 μm was 3.5 and 10.8 fs^2 mm^{-1}, respectively, (790 nm) and -9.6 and -7.8 fs^2 mm^{-1}, respectively (850 nm). The emerging emission spectra exhibit at all pump waves the oscillations with a period of 2 – 5 THz, which are typical for the SPM generation of a continuum.

S.M.Kobtsev, S.V.Kukarin, N.V.Fateev Novosibirsk State University, ul. Pirogova 2, 630090 Novosibirsk, Russia; e-mail: kobtsev@lab.nsu.ru

Received 5 September 2001
Kvantovaya Elektronika **32** (1) 11 – 13 (2002)
Translated by M.N.Sapozhnikov

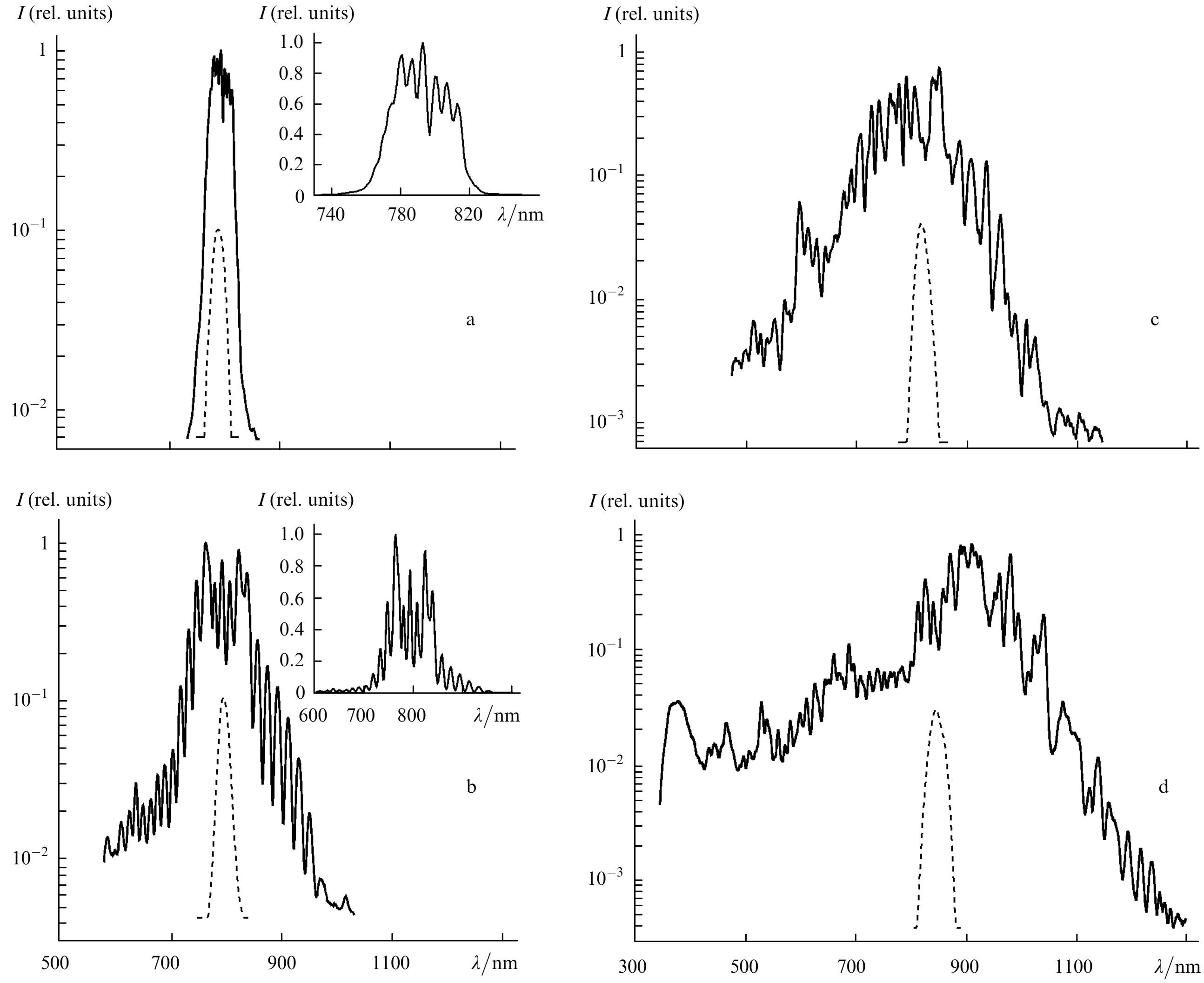

Figure 1. Spectral radiation distribution at the output of a microfibre of diameter 2.8 μm pumped by femtosecond pulses at 789 (a), 797 (b), 819 (c), and 847 nm (d) (solid curves) and spectra of pump pulses (dashed curves). The spectra in inserts are presented at a linear scale.

Fig. 1 shows the spectra of emission coming from a microfibre of diameter 2.8 μm and length 14 cm obtained upon pumping by femtosecond pulses from the Ti:sapphire laser at different wavelengths. The average radiation power emerging from the microfibre was the same and equal to 45 mW, while the profile of the transverse distribution of the output radiation was close to a Gaussian. When the pump wavelength was changed from 789 to 847 nm, the spectral distribution of the output radiation at the −20 dB level had the following boundaries: 742−840 nm (for the 789-nm pump wavelength), 580−958 nm (797 nm), 515−1010 nm (819 nm), and 350−1140 nm (847nm). The spectral width of the output radiation increased from 98 to 790 nm with increasing the pump wave. At the pump wavelength of 797 nm, which was close to λ_d for the microfibre, we observed the expected [9] partial concentration of the radiation energy in the central part of the detected spectrum in two spectral regions with maxima at 762 and 823 nm (see insert in Fig. 1b).

The results obtained can be qualitatively interpreted as follows. The initial positive chirp of pulses decreases in the region of anomalous GVD of the microfibre (for the pump wavelength above 800 nm), which is equivalent, in the case of fixed average power of the output radiation, to the increase in the peak power of pulses due to their compression. This results in the spectral broadening of pulses caused by the SPM with decreasing GVD in the region between 790 and 850 nm.

Thus, we have achieved the eight-fold variation in the width of the continuum at the −20 dB level by tuning chirped ultrashort pump pulses over ~ 60 nm in the region of the GVD sign change in a germanium-doped silica fibre with a core of diameter 2.8 μm entirely bordering air. The average spectral radiation density of the continuum was 0.46−0.06 mW nm^{-1}.

Acknowledgements. This work was supported by UTAR Scientific Company (Canada).

References

1. Knight J.C., Birks T.A., Russell P.St.J., Atkin D.M. *Opt. Lett.*, **21**, 1547 (1996).
2. Zheltikov A.M. *Usp. Fiz. Nauk*, **170**, 1203 (2000).
3. Liu X., Xu C., Knox W.H., Chandalia J.K., Eggleton B.J., Kosinski S.G., Windeler R.S. *Opt. Lett.*, **26**, 358 (2001).
4. Ranka J.K., Windeler R.S., Stentz A.J. *Opt. Lett.*, **25**, 796 (2000).
5. Fedotov A.B., Zheltikov A.M., Mel'nikov L.A., Tarasevich A.P., Linde D. *Pis'ma Zh. Eksp. Teor. Fiz.*, **71**, 281 (2000).

6. Ranka J.K., Windeler R.S., Stentz A.J. *Tech. Digest of CLEO'99* (Washington, OSA, 1999, CPD8); *Opt. Lett.*, **25**, 25 (2000).
7. Wadsworth W.J., Knight J.C., Ortigosa-Blanch A., Arriaga J., Silvestre E., Mangan B.J., Russell P.St.J. *Proc. of XIV LEOS Ann. Meet.* (N.Y., IEEE, 1999, PD1.5).
8. Birks T.A., Wadsworth W.J., Russell P.St.J. *Tech. Digest of V Optoel. and Comm. Conf. OECC'2000* (Chiba, Japan, 2000, PD2-3) p. 20, 21; *Opt. Lett.*, **25**, 1415 (2000).
9. Agraval G. *Nelineinaya volokonnaya optika* (Nonlinear Fibre Optics) (Moscow: Mir, 1996).